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Gravitropic Responses of Five Maize Hybrid Roots to Temperature

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(HT 474), and Pioneer 3751 (PI 3751). We obtained seed from the maize breeder at Cornell University. Barlow *et al* (1993) have determined that initial angle is not correlated with final root angle; we confirmed this in a preliminary experiment with these hybrids.

Seeds were placed on germination paper with their embryonic axis perpendicular to the force of gravity (Figure 1). Seedling growth was restricted to a vertical plane with Plexiglas plates. These were bound together with bands and placed into 20-liter plastic bags. The bags were closed after approximately 500 ml. of distilled water was added. This provided moisture for the duration of the experiment. Seeds were placed into an unlit growth chamber at either 17.5°C, 20°C, 25°C, or 30°C.

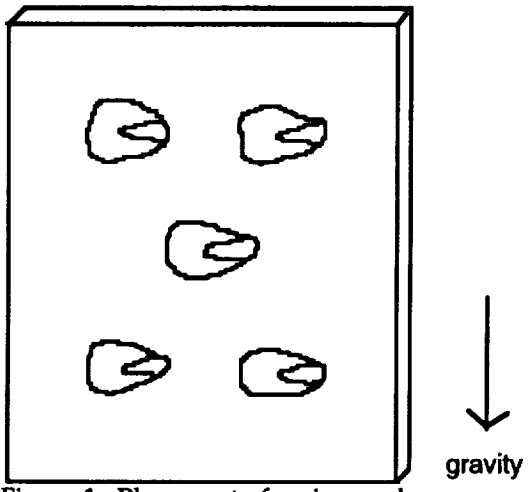

Figure 1: Placement of maize seeds on germination paper.

Seeds remained in the growth chamber for between 72 hours and 120 hours, depending on the temperature. Incubation lasted 72 hours at temperatures at or above 25° C, 96 hours at 20°C and 120 hours at 17.5°C. The length of incubation was adjusted so that all tap roots grew to approximately the same length (5-10 cm. long). We took measurements on initial and final shoot and root angles (Figure 2), with an angle of 0° indicating growth directly upwards, opposite to gravity, and an angle of 180° indicating growth directly downwards, towards the force of gravity. Roots and shoots were measured to the nearest 5°. In considering the large standard error inherent in radicle growth, the loss of accuracy attributable to this rounding-off is small (Ycas, 1980).

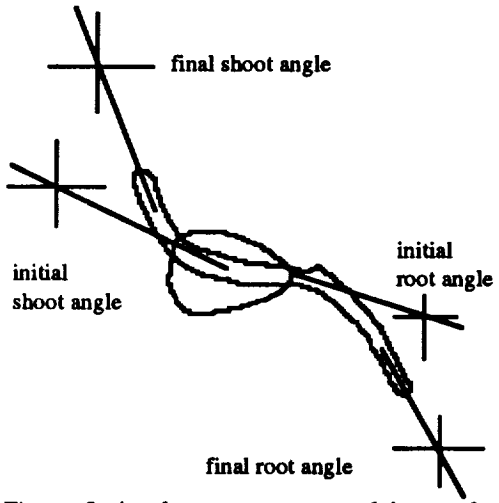

Figure 2: Angles were measured for seed placement, initial shoot angle, final shoot angle, initial root angle, and final root angle.

Each replicate consisted of 5 seeds of each hybrid, and the experiment was repeated 12 times to give a total of 60 seedlings measured per maize hybrid. Seeds of each hybrid were from the same seed lot throughout the study. We analyzed results using the AMMI statistical model (Additive Mean and Multiplicative Interaction model). AMMI includes a standard linear regression and ANOVA. This model not only evaluates differences between hybrids and temperatures, but also identifies interactions between the two factors.

Results and Discussion

Seed Angles

For all replicates, seed angles were approximately 90° (minimum value = 85°, maximum value = 90°). While some individual seeds did become oriented at other angles, this did not appear to bear on the final shoot or root angles, although the initial shoot angle of these seedlings may have been somewhat affected.

Initial Shoot Angles

CG 4327 and DK 524 patterns of initial shoot angles were significantly different from all other hybrids at each temperature. HT 474, EL 541, and PI 3751 had very similar patterns of initial shoot angle varying with temperature. For these three hybrids there was a distinct pattern of decreasing initial shoot angle (more vertical angles) with increasing temperature (see Figure 3). Analyzing seed angles, the unusual patterns of CG 4327 and DK 524 are not attributable to variant seed angles.

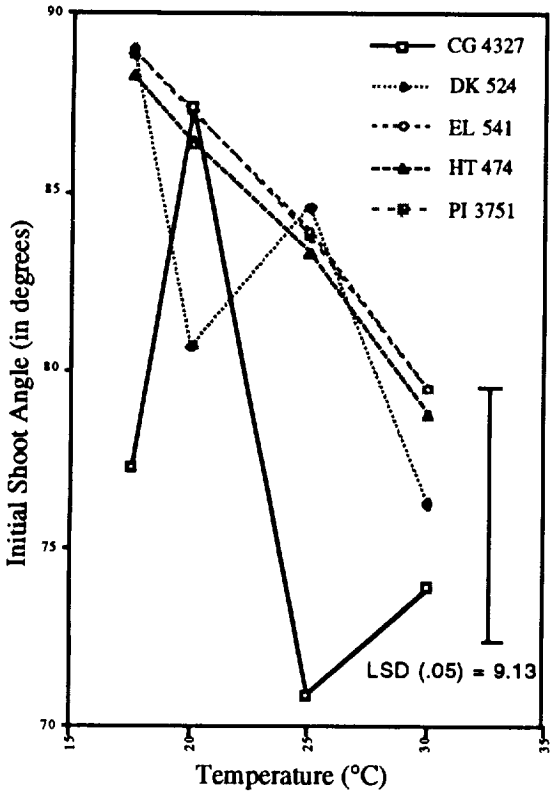

Figure 3. Initial shoot angles of five maize hybrid seedlings at four temperatures.

In addition, while overall there was no significant difference in initial shoot angles of all hybrids between 17.5°C and 20°C, there were significant differences between these two temperatures and the measurements at 25° C and 30°C (see Figure 4). There was a general trend of decreasing initial shoot angle with increasing temperature. No interaction between hybrid and temperature was apparent.

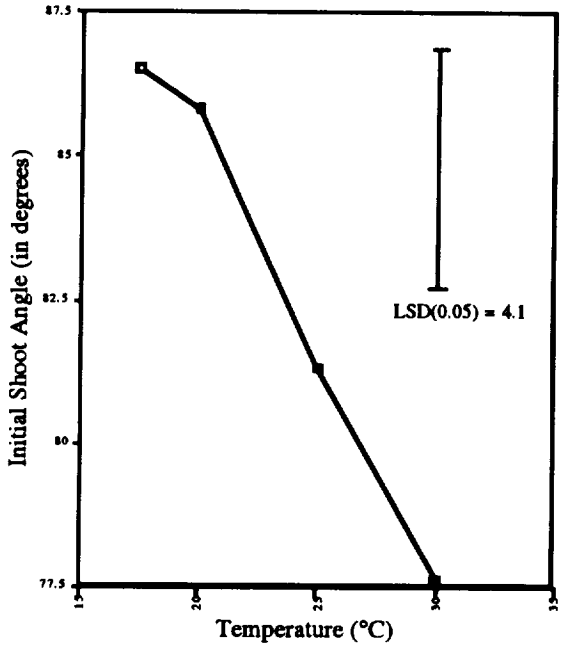

Figure 4. Initial shoot angles of maize seedlings at four temperatures.

Final Shoot Angles

CG 4327 final shoot angle continued to be significantly different from other hybrids. There also appeared differences between DK 524 and EL 541 although the response pattern was similar. Figure 5 shows the emergence of two patterns of response to temperature. CG 4327 shows one response pattern, while EL 541, HT 474 , DK 524 and PI 3751 show a second response pattern. CG 4327 shoots show the least response to varying temperature. The remaining four hybrids show a distinct pattern of more vertical shoot growth with increasing temperature.

The only non-significant difference in treatments was between 17.5°C and 20°C (Figure 6). In general, for the five hybrids studied, warmer temperatures produce more vertical shoot growth, while cooler temperatures produce shoot growth at an angle of about 30°. In addition, there was an interaction between the two factors,

indicating that some hybrids are responding more to temperature than others. This is apparent in Figure 5, in which CG 4327 is a non-responder compared to the other four hybrids studied.

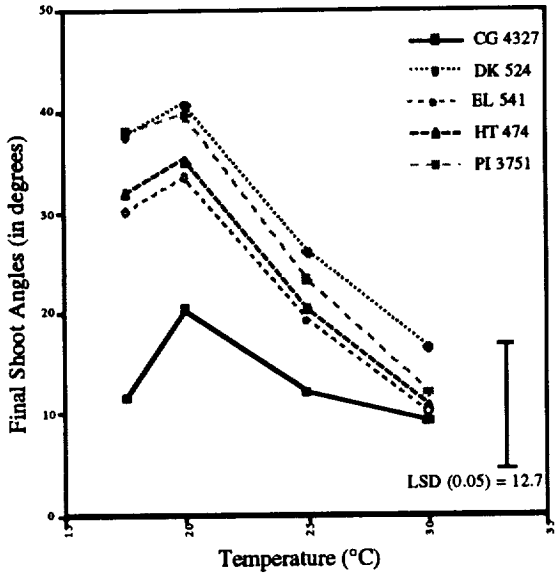

Figure 5: Final shoot angles of five maize hybrids at four temperatures.

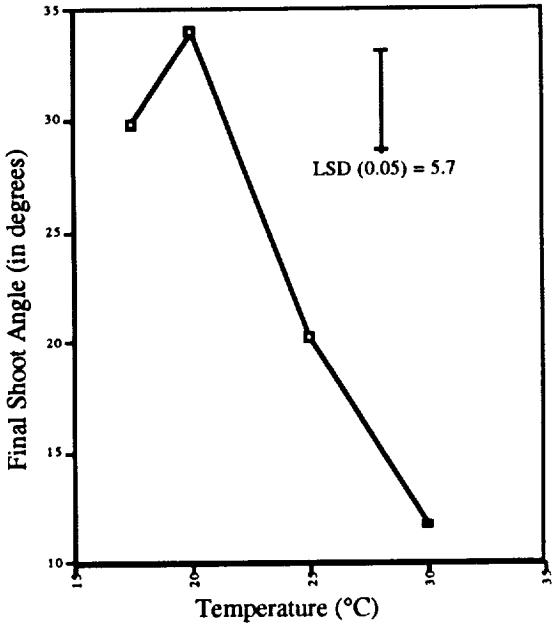

Figure 6. Final shoot angles of maize seedlings at four temperatures.

Initial Root Angles

Analysis of initial root angles indicated that PI 3751 and DK 524 were each significantly different from all other hybrids (Figure 7). Significant differences exist for different temperatures. Figure 8 indicates that 20°C was significantly different from all other temperatures when initial root angles of the five maize hybrids were averaged together. A temperature of 20°C produced initial tap root angles of about 117°, while at temperatures warmer or cooler, the initial angles were more vertical. 30°C produced the most vertical initial tap roots, with an average initial angle of about 130°.

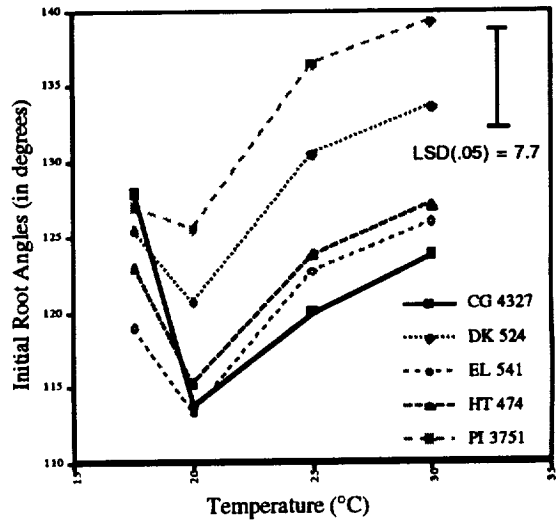

Figure 7. Initial root angles of five maize hybrid seedlings at four temperatures.

Final Root Angles

Statistical analysis of final root angle measurements indicated that there were significant differences apparent between all hybrids and all temperatures (Figure 9).

For the five hybrids, the average final root angles at 17.5°, 20° , 25°C, and 30°C were, respectively, 131.2°, 135.4°, 149.9° and 142.8 (Figure 10). The grand mean final root angle was 139.5°. For the five hybrids studied, the most vertical tap root growth

was achieved at 25°C. At temperatures either above or below this, tap roots tended to grow more horizontally.

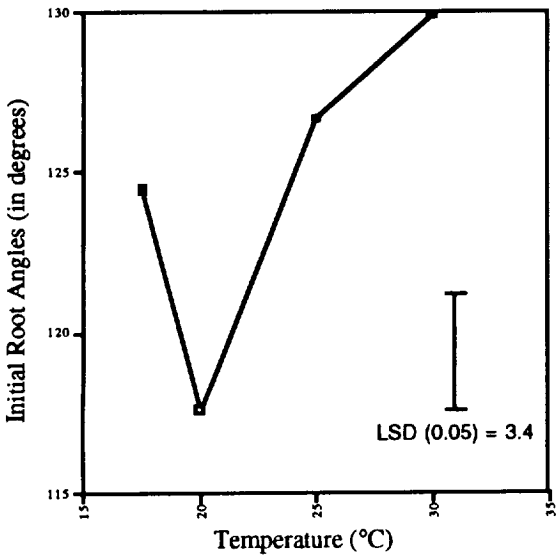

Figure 8. Initial root angles of maize seedlings at four temperatures.

CG 4327 and DK 524 showed no significant variations in final root angle between temperatures, while EL 541, HT 474 and PI 3751 all showed some significant variations between temperatures. While differences were not significant between 17.5° and 20°C, differences between 17.5° and 25°C were significant for those three hybrids. In addition, at 17.5°C the average final root angle of HT 474, 113°, was significantly different from CG 4327, DK 524, and PI 3751 final angles at that same temperature. At 25°C, PI 3751 had an average final root angle of 164.5°, which was significantly different from DK 524, EL 541, and HT 474. At all temperatures except 17.5°C, PI 3751 tap roots grew at angles about 15° closer to vertical than all other hybrids. This may be one reason for its continued success commercially; its ability to grow downward accurately and quickly may increase its access to deep water tables.

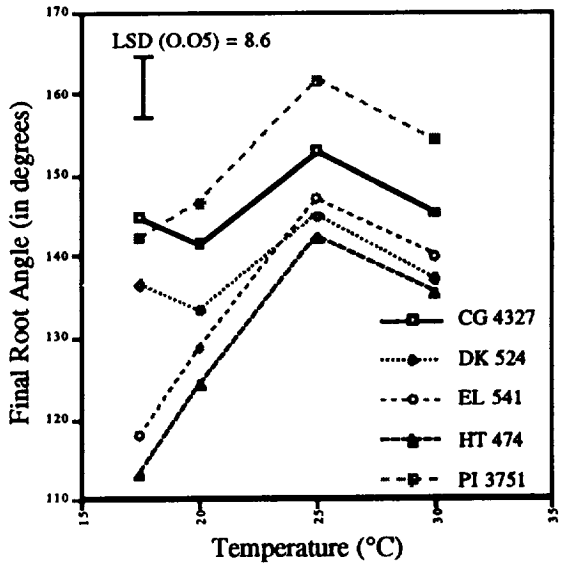

Figure 9. Final root angles of five maize hybrid seedlings at four temperatures.

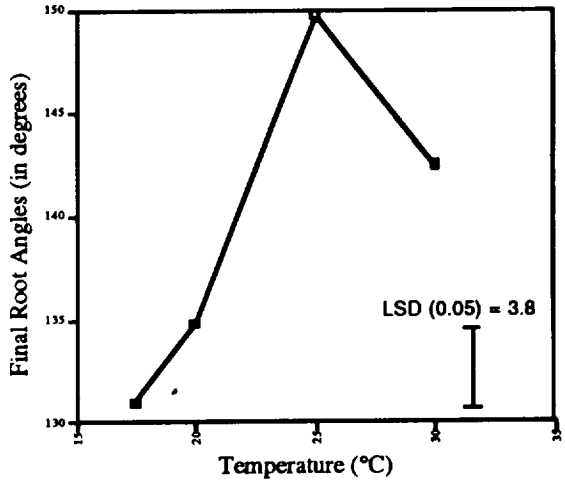

Figure 10. Final root angles of maize seedlings at four temperatures.

Concluding Remarks

Measurements of seedling initial and final shoot and tap root angles indicate that we cannot generalize a response pattern for a particular species. In maize, we have observed several varying response patterns for gravitropic response in shoots and roots to temperature. Two response patterns are

clearly seen in final shoot angles and three response patterns are seen in final tap root angles. In addition, by interpolating the data from Ycas (1980) on tap root angles, we may infer a fourth response pattern for this trait.

We are excited by these results, and maintain that gravitropic root response has a genetic component which may be modified by such environmental conditions as rhizosphere temperature and atmosphere. In evaluating five commercially available maize hybrids, we have determined that genetic variability for root characters is likely to be large.

Results obtained for final root angles varying with temperature are similar to the prediction Cooper (1973) makes for most plant metabolic and growth processes with temperature change. These results are promising and point us in several directions for future research. We will continue temperature studies using the inbred parents of these hybrids to evaluate gravitropic responses of those homozygous lines. In addition, we will evaluate the gravitropic response of maize hybrids to varying carbon dioxide levels. Preliminary results with CO_2 are quite promising and indicate that this gas also affects the gravitropic response of some maize hybrids. We also have in possession several tomato gravitropic mutants (diageotropica, lazy-1, lazy-2), which we hope to evaluate for response to both temperature and carbon dioxide. Through further research we hope to be able to identify lines that possess the gene or genes which are regulating gravitropic response to temperature and carbon dioxide.

Literature Cited

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APPENDIX

TABLE 1: Means of all hybrids and all treatments for the measurements taken. For hybrids, all temperatures are averaged together; for treatments, all hybrids are averaged together.

Variable	Seed Angle	Initial Shoot Angle	Final Shoot Angle	Initial Root Angle	Final Root Angle
HYBRID					
CG 4327	88.93	77.36	13.36	121.36	146.07
DK 524	86.40	82.65	30.27	127.53	137.97
EL 541	88.35	84.88	23.28	120.16	133.49
HT 474	89.17	84.22	24.56	122.31	128.76
PI 3751	87.73	84.86	28.26	132.06	151.13
TREATMENT					
17.5°C	87.78	86.47	29.82	124.46	130.92
20°C	89.58	85.79	33.96	117.65	134.83
25°C	87.18	81.31	20.25	126.68	149.79
30°C	87.93	77.61	11.73	129.95	142.40